

**Federal Communications Commission
Office of Engineering and Technology
Laboratory Division**

June 22, 2020

Draft Laboratory Division Publications Report

Title: MIMO Antenna Gain Measurement

Short Title: MIMO Antenna Gain Measurement

Reason: Adding a new Attachment to provide Guidance to address calculating directional gain of multi-antenna systems, as provided in publications 662911 D01 and D02.

Notes for this Draft:

- It is permitted to use this attachment D03 as guidance during the draft review period for demonstrating and documenting compliance for an equipment authorization.
- 388624 D02 Pre-Approval Guidance List will be updated to require a PAG when directional gain of an antenna system is measured in lieu of calculations. Directional antenna gain measurement procedure and measurement test results are to be provided as test report exhibits as stated in publication 662911 D03.

Publication: 662911

Keyword/Subject:

Measurement of Transmitters with Multiple Output, MIMO, Smart Antenna

Question: What is the guidance for measurement of output emission of devices that employ single transmitter with multiple outputs or systems with multiple transmitters operating simultaneously in the same frequency band?

Answer: The attached document, 662911 D01 Multiple Transmitter Output v02r01 provides guidance for measurements of conducted output emissions of devices that employ a single transmitter with multiple outputs in the same band. The guidance applies to devices that transmit on multiple antennas simultaneously in the same band through a coordinated process. Examples include, but are not limited to, devices employing beamforming or multiple-input and multiple-

output (MIMO.) This guidance applies to both licensed and unlicensed devices whenever the FCC rules call for conducted output measurements. Guidance is provided for in-band, out-of-band, and spurious emission measurements.

The attached document, 662911 D02 MIMO with Cross-Polarized Antennas v01, provides additional guidance for measurements of both conducted output emissions and radiated emissions from devices that have two outputs driving linearly polarized antennas that are cross-polarized with respect to each other.

Attachment 62911 D03 MIMO Antenna Gain Measurement provides Guidance to address calculating directional gain of multi-antenna systems.

The attached technical report, OET 13TR1003 Directional Gain of 802 11 MIMO with CDD 04 05 2013, provides the technical basis for array gain formulas included in 662911 D01 for IEEE 802.11 transmissions using cyclic delay diversity.

Attachment List:

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662911 D01 Multiple Transmitter Output v02r01 **

662911 D02 MIMO with Cross Polarized Antenna v01 **

[662911 D03 MIMO Antenna Gain Measurement v01 *](#)

OET 13TR1003 Directional Gain of 802 11 MIMO with CDD 04 05 2013**

* Attachment that is being posted for public comment as a draft.

** Attachments not under review and is currently published in 662911

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**Provision to Allow Measurement of Directional Gain of Multi-Antenna Systems for
Compliance Verification**

1. PURPOSE

Calculating directional gain of multi-antenna systems, as provided in publications 662911 D01 and D02, may overestimate the actual gain for the following reasons:

- The directional gain calculation does not consider the mutual interactions between radiating elements.
- Impedance mismatch, between radiating elements and drivers, matching networks, etc., is not accounted for.
- Physical separation between the radiating elements might be too large, relative to the size of the elements, so the elements do not have the same phase center
- The directional gain calculation provides the maximum gain of a multi-antenna system that is theoretically possible for in-band operation and under ideal conditions. It does not consider the fact that the directional gain may be degraded outside of the passband of the antenna system (out of band gain)

As a result, applicants that may rely on directional gain of their system as a condition on compliance certification may have to pay a penalty if directional gain of the system is overestimated¹.

Alternatively, for compliance purposes, actual gain of an antenna system, when properly measured, may be used in lieu of calculation. This publication describes what steps test labs or manufacturers should take to present their antenna gain measurement results for review.

2. SCOPE

Properly- measured antenna gain results can be applied to EMC compliance measurements on devices and systems (including hosts with multiple modular transmitters) that transmit on multiple antennas simultaneously in the same or overlapping frequency ranges through a coordinated process. Examples include, but are not limited to, devices and systems employing beamforming or multiple-input and multiple-output (MIMO.) This guidance applies to both licensed and unlicensed devices wherever FCC

¹ For example, the conducted output power of certain DTS devices subject to §15.247 is based on the use of antennas with directional gains that do not exceed 6 dBi. If transmitting antennas of directional gain greater than 6 dBi are used, the conducted output power from the intentional radiator shall be reduced below the maximum value by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

rules call for conducted output measurements with limitations on antenna gain or where conducted output measurements are combined with directional antenna gain to demonstrate compliance with a radiated limit.

3. DEFINITIONS

Beam: Major lobe of the radiation pattern of an antenna or antenna system.

Multiple beams: Multiple peaks (major lobes) of the radiation pattern of an antenna or antenna system.

Gain: The gain of an antenna, in a specified direction $G(\theta, \varphi)$, is 4π times the ratio of the power radiated per unit solid angle in that direction $U(\theta, \varphi)$ to the net power available at the antenna connector P_{in} . This definition of gain is also referred to as realized gain since it accounts for impedance and polarization mismatches. Throughout this document, the term Gain shall imply realized gain. Additionally, the gain of an antenna is usually measured in the direction of its maximum (or peak) value, i.e., peak gain. The terms gain and peak gains are used interchangeably in this document.

4. POINTS TO CONSIDER BEFORE SUBMITTING RESULTS OF DIRECTIONAL GAIN MEASUREMENTS

It is permitted to provide appropriate antenna gain measurement results in lieu of theoretical calculations to demonstrate compliance. However, approval is on a case by case basis, and it is subject to pre-approval guidance (PAG) filing.

When submitting antenna gain measurement results, the following items should be addressed, as detailed in the sub-sections below:

- 1- Antenna System Description
- 2- Measurement Quantity
- 3- Measurement Method
- 4- Measurement Environment

4.1. Antenna System Description

Applicant must adequately describe the antennas or radiating elements comprising the antenna system. The description should identify the number of radiating elements, their types and their geometric placement. Applicant must also describe if the antenna system can generate multiple beams, and how many beams (simultaneously or sequentially) can be generated. If different system configurations can provide beams with different directivities and each beam can serve different application, then directional gain of each beam should be measured. Additionally, the worst-case scenario, of each configuration, needs to be determined and its directional gain needs to be measured.

Advanced antenna systems are usually capable of beam steering in both azimuth and elevation. If that is the case, then multiple configurations shall be identified and measured to verify:

- a) The (steered) beam with maximum gain
- b) The extent of steering capability

4.2. Measurement Quantity

The most important figure of merit is the directional gain of the antenna system. Directional antenna gain shall be measured over the whole frequency range or band of operation in which the device is authorized to operate (in-band gain). In cases where radiated out of band emission limits are investigated, conducted output measurements are sometimes combined with directional antenna gain to demonstrate compliance with the radiated limit. In those cases, out of band directional gain of the antenna system shall be measured. The out of band gain shall be measured over the whole frequency range that needs to be investigated.

In case of antenna systems with beam steering capability, radiation pattern of the antenna system shall clearly show maximum gain of the beam as it is steered beyond its boresight up to and including the minimum and maximum steering angle of the antenna.

4.3. Measurement Method

Applicant shall clearly describe the method used to perform directional gain measurements. Absolute gain measurement method or gain-transfer (gain comparison) method are among the more conventional methods that are commonly used for antenna gain measurements. However, novel measurement methods may be reviewed if applicant can provide a full description of the method including its applicability and its limitations.

4.4. Measurement Environment

Applicant shall fully describe the environment in which the directional antenna gain measurement is performed including the type of antenna range and anechoic chamber. The applicable frequency range of operation as well as limitations of each antenna range (rectangular or tapered chamber, compact antenna test range (CATR), Near field scanners, etc.) shall be clearly stated to demonstrate antenna range of choice is in fact capable of accurate gain measurement of the antenna under test over the frequency range that needs to be investigated.